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# Automated Control of Lighting and Fenestration

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
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Prepared for:

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# AUTOMATED CONTROL OF LIGHTING AND FENESTRATION

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**U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary***
**NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director***

## ABSTRACT

This paper describes a methodology for an automatic system for controlling the lighting and window shading in a commercial building. The system utilizes a microcomputer to monitor solar radiation and illumination levels and interior and exterior air temperatures, processing the input parameters to determine the optimum lighting level, window area, and solar film position to minimize building heating and cooling loads due to windows and lighting. The control methodology and logical flow are presented. The response of the system to various combinations of weather conditions is examined.

Keywords: automatic control; daylighting; lighting control; microprocessor; window management

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## NOMENCLATURE

A = area
DF = daylighting factor
I = illuminance
LP = lighting power
SF = shading factor
SR = solar radiation
T = temperature
$\Delta$T = temperature difference
U = thermal transmittance

Subscripts:

| | |
|---|---|
| d | = diffuse |
| F | = film |
| G | = glass or unshuttered window |
| I | = point of inflection |
| R | = reference point |
| S | = shutter or shuttered window |
| T | = total horizontal |
| V | = vertical |
| xa, xb | = x-intercept |
| out | = exterior |
| in | = interior |
| max | = maximum |
| min | = minimum |
| 0(zero) | = zero value |

## 1. INTRODUCTION

Building energy consumption is primarily due to heating, cooling and lighting demands. In many commercial buildings, the largest annual energy cost is for cooling, especially since core areas experience a temperature rise due to internal heat gains. Electric lighting impacts building energy requirements in two ways. First, the energy must be purchased to provide light. Second, the heat dissipated from the light fixtures will be a heat gain to the interior building space. This may be a benefit in winter if heating is needed, while under summer conditions cooling load will increase. However, even in winter it is possible that excessive heat gain due to solar radiation or lighting could result in overheating, unless some of the heat can be distributed to other parts of the building.

Large window areas will result in high daylight levels, thereby reducing electric lighting requirements. However, large windows also allow more conductive heat transfer, as well as increased solar heat gain due to transmitted solar radiation. Window heat transfer due to conduction will depend upon the interior and exterior air temperatures, and heat flow can occur in either direction. Thus, a trade-off must be made, between reducing lighting load through the use of large windows, and increasing window heat transfer. In most cases, window area is fixed, so any adjustment of the heat transfer characteristics of the window is accomplished through the use of shades and blinds, which are adjustable, or films and screens, which are usually fixed. These would be examples of a strategy called window management, whereby the thermal and/or visual characteristics of a window system can be selectively altered as desired, either manually or automatically.

Control of window heat exchange and lighting loads can be accomplished through window management and daylight utilization. Window management devices include solar films and screens, shutters, drapes, and louvers. Many types of lighting controls are available to enable continuous dimming of lighting in response to daylighting levels [1,2,3]. The beneficial aspects of controllable window management and daylight utilization are well recorded [4,5].

This paper will focus on the net effect of window management and lighting level on building heating and cooling requirements, and how to reduce these requirements through the use of a microprocessor-based control system. An additional benefit of this type of control system is that peak heating and cooling loads can be reduced, thereby enabling use of smaller heating and cooling systems. Such systems are beginning to be used in buildings for various control purposes [6]. An automatic control system consisting of a microcomputer, a group of sensors, and output actuators, determines the optimum window area and decides whether a reflective film should be lowered. Window area can be adjusted through the use of motorized insulating shutters, and the reflective film is tracked at the window frame. Thus, the reflective film can be raised or lowered, and the position of the shutters controlled in response to the decision of the controller. The purpose of the reflective film is to reduce solar heat gain (through reflection) and to reduce radiative heat transfer between the room and the interior window surface (due to lower surface emittance). The shutter would be used to reduce window conductive heat transfer when daylighting

is not needed, or when the benefit of daylighting is outweighed by undesirable window heat transfer.

The basic operation of the system is as follows. The interior air temperature is compared to a reference value. If these two agree within a specified bandwidth, the controller will attempt to maintain that temperature by configuring the windows and lighting for zero heat gain. If the interior air temperature should rise above the acceptable band, the controller will minimize heat gain. Conversely, if the temperature falls below the band, heat gain would be maximized. This measurement and decision process would be repeated at cyclic intervals. The illumination reference level is the level which must be maintained, through a combination of daylighting (natural light) and electric lighting. The reference level could be set to zero for non-working hours and weekends. Manual override lighting switches would enable lights to be turned on in different areas as needed for maintenance crews and after-hours building occupants.

Daily, weekly or annual control schedules could easily be superposed on the system, enabling night setback, weekend shutdown or any other operating procedures to be implemented. The system could also control the HVAC equipment, calling for heating and cooling as needed, in response to building air temperature. This report deals only with the portion of the control system which is controlling the lighting and window management.

## 2. LIGHTING AND FENESTRATION CONTROL SYSTEM

A schematic of a typical system is shown in figure 1. Three window options are available: first, a double-pane clear window; second, the same window with a reflective film which can be automatically raised or lowered; third, an insulating shutter. The shutter can be opened and closed any amount, so glass area can be varied continuously from 0 to 100 percent of total window area. Any combination of glass, film and shutter can be used, except, for simplicity, the film must be completely up or down.

Performing a heat balance between the exterior and a typical office module, and including only those terms which are related to window heat exchange or lighting, the following equation is obtained:

$$\text{Heat Gain} = Q_L = LP + TRANS + COND + CONV + RAD \qquad (1)$$

where LP = lighting power
TRANS = transmitted solar radiation
COND = conductive heat transfer
CONV = convective heat transfer
RAD = radiative heat transfer

If eq. (1) is negative, a heat loss is indicated. If eq. (1) is positive, a heat gain results. At some point, $Q_L$ may be zero, indicating that the combined effect of window and lighting on room heat gain is zero.

The transmitted solar radiation term of eq. (1) can be evaluated as

$$\text{TRANS} = SF(SR_V)A_G \tag{2}$$

where $SF$ = shading factor
$SR_V$ = vertical solar radiation
$A_G$ = glass area

The shading factor is a dimensionless parameter which is the ratio of solar heat gain to incident vertical solar radiation, for each window option. Solar heat gain associated with a window consists of two components, namely directly transmitted solar radiation, and absorbed solar radiation which is transmitted to the building space by convection and radiation. The transmittance of a window is dependent upon the angle of incidence of the incident solar radiation, however, the angular distribution of the incident solar radiation is very difficult to measure, and typically not known. Thus, a simplifying assumption is made to treat the shading factor as being a constant. The value of SF for the reflective film option would be less than that for the clear glass, while SF for the shutter is equal to zero.

The heat gain due to conduction, convection and radiation can be evaluated as

$$\text{COND} + \text{CONV} + \text{RAD} = U_S A_S \Delta T + U_G A_G \Delta T \tag{3}$$

where $U$ = overall transmittance
$\Delta T$ = temperature difference $(T_{OUT} - T_{IN})$
$A$ = surface area
Subscript S = shutter, G = glass

The required lighting power can be determined by consideration of the required illumination level ($I_R$). As the level of daylight increases, lighting power can be reduced. If the actual interior illumination ($I_I$) meets or exceeds the reference level, $I_R$, no lighting is needed. That is:

$$\frac{(I_R - I_I)}{I_R} LP_{max} = LP \tag{4}$$

where $LP_{max}$ = maximum lighting power

It is possible to calculate the level of daylight with each window option, based on the exterior vertical illumination, which can be easily and accurately measured. The daylight factor method uses a factor (DF) which is to be multiplied by the exterior vertical illuminance ($I_V$) to determine the interior illuminance $I_I$ [7]. The daylight factor can be measured or calculated, and typically is less than 10 percent. This factor is scaled proportionally with window area by the area ratio $A_G/A_T$. Thus:

$$I_I = I_V(DF)\frac{A_G}{A_T} \tag{5}$$

where $A_T$ = total fenestration area.

When direct beam solar radiation (and illumination) is incident upon a window, the transmitted direct beam may be excessive, from the standpoints of glare and local overheating near the window. In addition, direct beam illuminance may not be as effective in providing work-plane daylight, because the direct beam frequently strikes the floor and must undergo multiple reflections before reaching the task surface. The control system could be programmed to account for these effects. Glare and local overheating could be minimized by setting a maximum limit on transmitted solar radiation, so that the reflective film would be used whenever a high level of direct beam solar radiation was incident upon the window. A typical value for the maximum limit would be 500 $w/m^2$, since diffuse radiation rarely exceeds this value [8]. This limit could be set and adjusted by the building occupants as required. The effect of direct beam daylight possibly being less effective than diffuse daylight at providing work-plane illuminance could be handled by derating. Levels of incident diffuse illuminance rarely exceed 60,000 lux [8]; if the incident illuminance exceeded that amount, the calculation of interior daylight could be made using a lower value for the incident illuminance. The adjusted value could be chosen conservatively to be 60,000 lux, or perhaps chosen to be 60,000 lux plus a percentage of the illuminance over 60,000 lux.

Both of these direct beam effects occur only for windows facing the sun when skies are clear. Thus, the potential for problems exists for only a small percentage of the hours of the year, so neglecting direct beam effects would probably have a small impact on building energy or occupant comfort. Glare or overheating problems could also be overcome when necessary by manual over-ride of the window management system by the building occupants. Since the potential for problems associated with direct beam solar radiation is highly dependent upon individual building designs and locations, the remainder of the analysis assumes that no special control strategies are implemented for direct beam solar radiation.

If the shutters are in a partially closed position, some heat exchange will be occurring through both the glass portion of the total fenestration area and the portion covered with the shutter. Considering this and eqs. (2-5), net heat gain due to windows and lighting is:

$$Q_L = U_G A_G \Delta T + U_S (A_T - A_G) \Delta T + \frac{I_R - I_V (DF)\left(\frac{A_G}{A_T}\right)}{I_R} LP_{max} + (SF)(SR_V)(A_G) \qquad (6)$$

This equation can be rearranged to yield:

$$Q_L = A_G \left[ (U_G - U_S)\,\Delta T + (SF)(SR_V) - \frac{(DF)(I_V)(LP_{max})}{I_R\, A_T} \right] + LP_{max} + (U_S)(A_T)(\Delta T) \qquad (7)$$

$$= A_G[K_1 + K_2 - K_3] + K_4 + K_5 \tag{8}$$

Room heat gain $Q_L$ is seen to be a function of window area $A_G$ plus two constant terms. The control program determines the optimum window area, which is the portion of the window not covered by an insulating shutter, for each window option, and then compares each option to determine the most desirable one.

For each window configuration at any particular instant in time, all the variables on the right side of eq. (7) are known, either as constants or measured values, except for the glass area, $A_G$. $A_G$ is determined based upon whether the building is in a heating mode, cooling mode, or within the acceptable temperature band. For example, if it is desired that the indoor air temperature be maintained within a 5°F band, then the modes would be determined according to table 1.

Table 1

| Condition | Mode | Response | |
|---|---|---|---|
| $\lvert T_R - T_{IN} \rvert < 2.5$ | I | $Q_L \rightarrow 0$ | Stable |
| $T_R - T_{IN} > 2.5$ | II | $Q_L \rightarrow max$ | Heating |
| $T_R - T_{IN} < -2.5$ | III | $Q_L \rightarrow min$ | Cooling |

(9)

where $T_R$ = reference temperature (setpoint), °F.

To illustrate the use of the control methodology, an example is presented in the following section.

Shading factors, daylight factors and U-values for the different window options used in the example are listed in Table 2. These are typical values for the parameters for this system configuration. Other types of window treatments could easily be accommodated by insertion of different values.

Table 2

| Option | U | SF | DF |
|---|---|---|---|
| Double Pane | 0.58 | 0.87 | 0.10 |
| w/film | 0.38 | 0.17 | 0.03 |
| w/shutters | 0.10 | 0 | 0 |

## 3. CONTROLLER OPERATION

When the control system is in operation, the values from Table 2 are substituted into eq. (7), and the values of the K constants are determined for the case of clear glass and of glass with film. The optimum value of $A_G$ will depend upon the mode (i.e. heating, cooling, stable) and on the values of the K's. $K_4$ and $K_5$ function as a constant offset, and the y-intercept, $(K_4 + K_5)$, can be negative or positive. Since $K_4$ equals $LP_{max}$, it is always positive. $K_1$ and $K_5$ can be either negative or positive, depending upon the indoor-outdoor temperature difference. $K_2$ must always be positive, since solar radiation level is never negative.

From eq. (8), when $A_G = 0$

$$Q_L = K_4 + K_5 \tag{10}$$

As window area $A_G$ increases, $Q_L$ can increase or decrease. If $(K_1 + K_2 - K_3)$ is negative, the slope of $Q_L$ will decrease with increasing $A_G$; if $(K_1 + K_2 - K_3)$ is positive, $Q_L$ will increase.

Eq. (7) does not hold when the daylight level exceeds the illumination set point. When this occurs, eq. (7) would have a negative lighting power term. Since this is impossible, eq. (7) must be modified so that lighting power never becomes negative. A point of inflection in the plot of $Q_L$ will occur when the required lighting power reaches zero. Under some conditions this point will not be reached unless window area exceeds the maximum possible (total window area $A_T$). At other times, this may occur at an intermediate window area.

The window area at the inflection point is:

$$A_I = \frac{I_R}{I_V} \frac{A_T}{DF} \tag{11}$$

where $A_I$ = glass area at inflection

If $A_I$ is greater than zero and less than or equal to the total window area, a change in slope of $Q_L$ will occur at some intermediate window area. For this value of $A_I$ and these conditions, $I_R$ will equal $I_I$, so no lighting will be needed. At this point $K_3$ and $K_4$ cancel each other. For any greater values of $A_G$, the heat gain is given by eq. (12), since no more decrease in lighting power can occur.

$$Q_L = A_G(K_1 + K_2) + K_5 \tag{12}$$

The signs of the conduction terms, $K_1$, and $K_5$, are dependent upon whether interior temperature is warmer or colder than exterior. Since $K_3$ is positive,

$$K_1 + K_2 > K_1 + K_2 - K_3 \tag{13}$$

Considering eqs. (8, 12, 13) it is apparent that the slope of $Q_L$ must always increase following an inflection. Several possibilities for the $Q_L$ vs. $A_G$ plot

are summarized in figure 2. In 2a, the initial slope is positive, increasing after inflection. However, the slope of b changes sign at the inflection. Plot c has an x-intercept (zero $Q_L$) and d starts out negative and continues decreasing. Other variations are possible, but all would be treated the same way in the analysis. The optimum value for $A_G$ is dependent upon the mode; that is, whether the aim is to maximize, minimize or set to zero the heat gain $Q_L$. In all cases, the proper value of $A_G$ is one of the following:

$A_0$ = zero glass area
$A_I$ = area at inflection
$A_x$ = area at x-intercept
$A_T$ = maximum window area.

This is due to the nature of the relationship between $Q_L$ and $A_G$. As shown in figure 2, $Q_L$ is given by two linear functions, one before the inflection point and another after. The values of $Q_L$ that are of interest are those within the range of admissible window areas which are maximums ($Q_{max}$), minimums ($Q_{min}$), or closest to zero ($Q_0$) depending on the mode. By inspection, the max and min points must always occur at $A_0$, $A_T$ or $A_I$. When $Q_L$ equals zero for an admissible window area, an exact solution is found. If no acceptable x-intercept is found, the value of $Q_L$ closest to zero will again occur either at $A_0$, $A_T$ or $A_I$.

Analysis of various combinations of the K constants enables the proper value for $A_G$ to be selected for $Q_{max}$, $Q_{min}$ or $Q_0$. For example, if $Q_L$ is less than zero when window area $A_G$ equals zero, and the initial slope ($K_1 + K_2 - K_3$) is negative, an x-intercept can only occur if there is a change in slope sign. If that is the case, $Q_L$ will be at a minimum at the point of inflection (change of slope). If the initial slope ($K_1 + K_2 - K_3$) is positive, $Q_{min}$ will occur at $A_0$ since all other areas would result in larger $Q_L$, and $Q_{max}$ will occur at $A_T$. However, if there is no change in slope sign and the initial value of $Q_L$ is negative, $Q_L$ will be maximum and closest to zero at $A_0$, and minimum at $A_T$. Conversely, again with no change in slope sign, if the initial value of $Q_L$ is negative and the initial slope is positive, $Q_L$ will be minimum at $A_0$, and maximum at $A_T$. If an x-intercept occurs, that value of $A_G$ would result in $Q_L$ equal to zero. If no x-intercept is possible, the value of $Q_L$ closest to zero would occur at $A_T$. In a similar manner, the optimum value for $A_G$ can be determined for each case.

An x-intercept will occur when $Q_L = 0$, so from eqs. (8) and (12), the window area for this case would be given by:

$$A_{xa} = \frac{K_4 + K_5}{K_3 - K_1 - K_2} \qquad \text{for } A_x < A_I \tag{14a}$$

or

$$A_{xb} = -\frac{K_5}{K_1 + K_2} \qquad \text{for } A_x > A_I \tag{14b}$$

Eq. (14a) is the x-intercept of eq. (8), while eq. (14b) is the x-intercept of eq. (12). To determine if an x-intercept occurs for either function while in

the proper range of window areas, two comparisons must be made. First, a solution to eq. (14a) must also lie between the minimum window area and the area at the point of inflection. This is because if $A_{xa}$ is greater than $A_I$, eq. (14b) must be used, since eq. (14a) is only valid up to window areas equal to $A_I$. Similarly, from eq. (14b), $A_{xb}$ must lie between $A_I$ and the total window area, $A_T$. It is possible that no x-intercept will occur for permissible window areas, or two x-intercepts can occur if a change in slope sign occurs while $Q_L$ is slightly negative. If two acceptable x-intercepts are found, the one with the largest window area is used, since larger window areas are usually considered desirable from an occupant standpoint. This convention could easily be reversed or modified to meet occupant needs.

In all cases, it is necessary to determine if a change in slope sign occurs for $Q_L$, since that presents a special case. Comparing eqs. (8) and (13), it is seen that a change in slope sign will occur if:

$$K_1 + K_2 > 0 \qquad \text{and} \qquad K_3 > K_1 + K_2 \tag{15}$$

When this is the case, the inflection point must be a minimum, since the slope must increase after inflection, and therefore must be positive after sign change, and negative before the inflection.

The values of $K_1$ through $K_5$, along with the values of $A_x$, $A_I$, $A_O$, $A_T$, are seen to enable determination of the optimum window area for the clear glass and film cases. The heating or cooling loads are compared for each option to determine the most desirable option as required by the mode. When that alternative is determined, the proper control signals can be sent to the lighting system, film controller, and shutter controller. The control signals consist of an up or down command to tracked reflective film, a position command to the shutters to set window area, and a level signal to the lighting controller.

In an actual operation, adjustments could be made to the reference inputs to limit the minimum glass area to some percentage during working hours, or to provide nightly setback. A complete building control system could include analysis of heat transfer through other portions of the building envelope, to enable the lighting and fenestration energy effects to be more closely matched to the needs of the entire building. A rate-of-change procedure could be included to enable the control system to anticipate future load demands. Another alternative would be to base the control strategy on minimizing building energy requirements rather than heating and cooling loads. This could be accomplished in a similar manner.

## 4. CONTROL PROGRAM AND SIMULATION

A FORTRAN computer program was developed to simulate the performance of the control system. The program reads sample input data, such as U, DF, SF, and $I_R$, as well as typical values of solar radiation $SR_V$ and vertical illumination, and indoor and outdoor air temperature. The program analyzes the input parameters and determines the best window/lighting alternative. The optimum configuration (film up or down) and glass area are printed for each case, along

with the input data and mode. The program listing and sample output are contained in figures 3 and 4 respectively.

## 5. CONCLUSION

A digital microprocessor control system for controlling window shading and lighting is seen to be of value in reducing building heating and cooling loads. This type of system and methodology could easily be integrated into an overall building control system, which would enable other building heat transfer processes to be included in the determination of window option and area. Other window options could be included, such as adjustable louvers or shades. The options included in this analysis, namely double-pane glass, glass with reflective film, and fully adjustable insulating shutters, were chosen merely as examples of typical window management systems.

While the heat transfer processes included in this analysis were treated as linear functions, more complex relations could easily be accommodated, since nearly any function can be programmed on a digital computer.

Once the components of an actual control system are chosen, the operating and control programs can easily be stored and executed with a small integrated circuit microprocessor. The entire system would consist of several radiation and illumination sensors, connected to the microprocessor through an analog-to-digital converter. Desired operating parameters, such as reference temperature and illumination or maximum and minimum allowable window area, could be entered using a numeric key pad. Such a system would be inexpensive to construct and operate, and should perform reliably. The microprocessor would direct the operation of an output controller which would send the control signals to the lighting, shutters and tracked film.

For a control system configured as the one described in this report, analysis of the response to changes in the values of the input parameters, and the determination of the optimum un-shuttered window area, is aided through the use of five constants which are determined based on the window system parameters and the measured levels of solar radiation and illumination. When in operation, the controller would sample the input sensors and adjust the shutters and/or film position if needed at a cyclic interval as determined by the building occupants. The system could sample and adjust continuously, or at five or ten minute intervals to avoid rapid repeated changes which might prove annoying to occupants.

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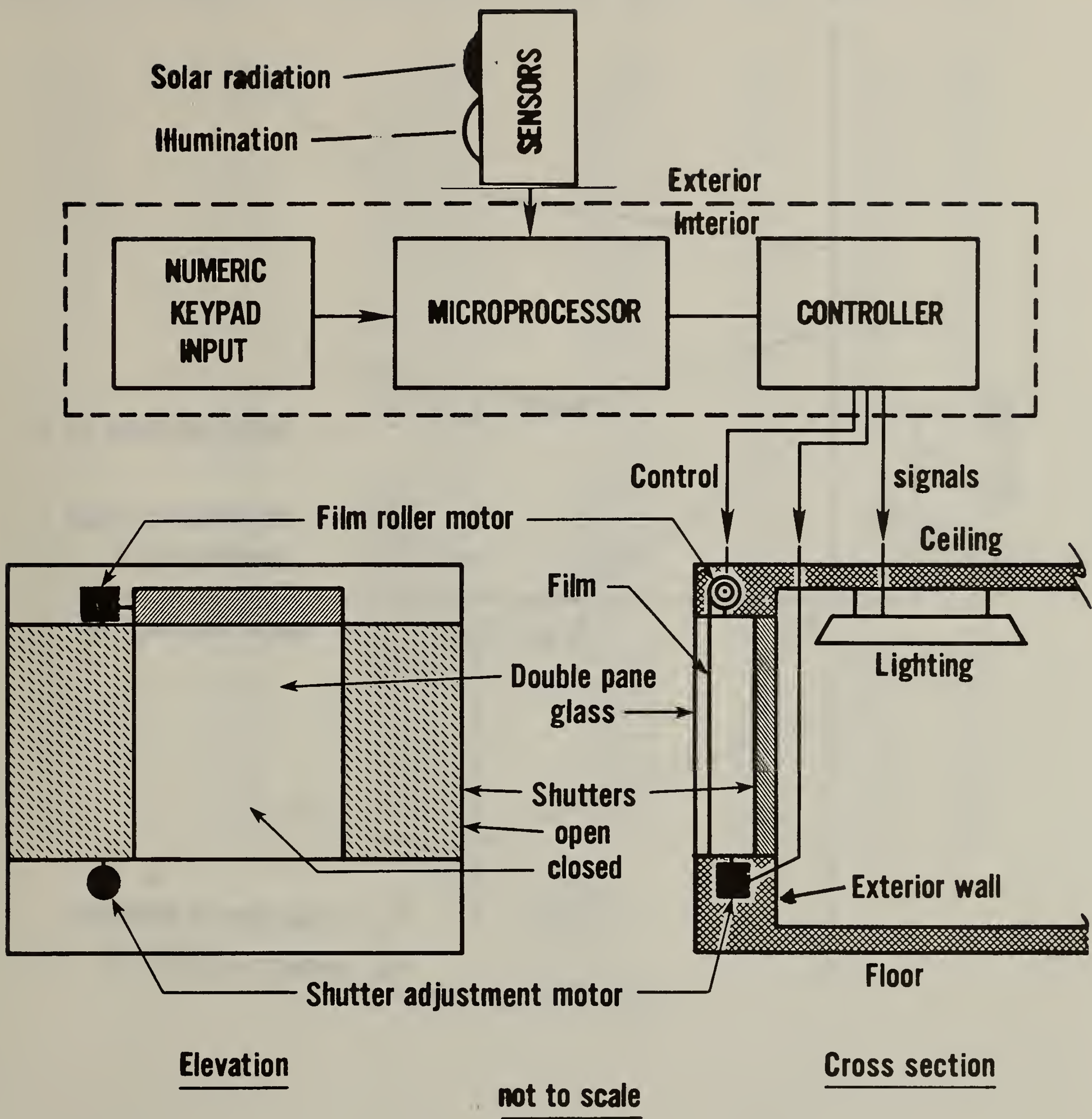


Figure 1. Schematic of typical control systems

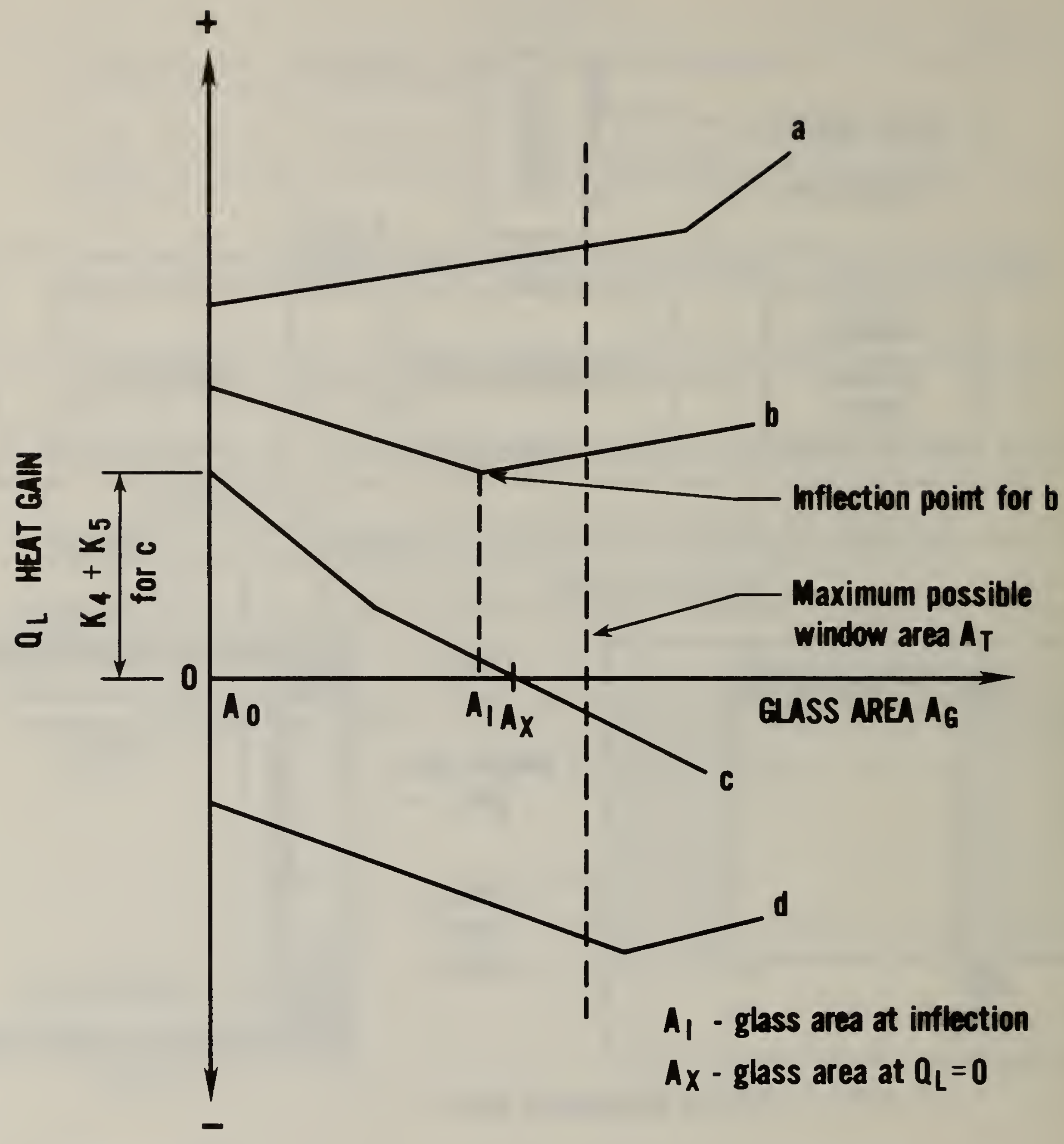


Figure 2. Heat gain $Q_L$ as a function of glass area $A_G$

| Outdoor Temp. (°F) TO | Indoor Temp. (°F) TI | Vertical Illum. (lux) IV | Vertical Irrad. ($wm^{-2}$) SRV | Area Ratio AR | OPT** | Mode* |
|---|---|---|---|---|---|---|
| 35.00 | 70.00 | 1.00 | 1.00 | 0.00 | 1.00 | 2.00 |
| 35.00 | 7.00 | 5000.00 | 100.00 | 0.00 | 2.00 | 2.00 |
| 35.00 | 70.00 | 20000.00 | 500.00 | 1.00 | 1.00 | 2.00 |
| 35.00 | 70.00 | 50000.00 | 1000.00 | 1.00 | 1.00 | 2.00 |
| 55.00 | 70.00 | 5000.00 | 100.00 | 0.00 | 1.00 | 2.00 |
| 55.00 | 75.00 | 5000.00 | 100.00 | 0.00 | 1.00 | 1.00 |
| 55.00 | 75.00 | 20000.00 | 500.00 | .40 | 2.00 | 1.00 |
| 55.00 | 75.00 | 50000.00 | 1000.00 | 0.00 | 1.00 | 1.00 |
| 75.00 | 76.00 | 5000.00 | 100.00 | 0.00 | 1.00 | 1.00 |
| 75.00 | 76.00 | 20000.00 | 500.00 | 0.4 | 2.00 | 1.00 |
| 75.00 | 76.00 | 30000.00 | 250.00 | 0.00 | 1.00 | 1.00 |
| 95.00 | 75.00 | 20000.00 | 500.00 | 0.00 | 1.00 | 1.00 |
| 95.00 | 80.00 | 20000.00 | 500.00 | 1.00 | 2.00 | 3.00 |
| 95.00 | 80.00 | 50000.00 | 1000.0 | 0.00 | 1.00 | 3.00 |
| 95.00 | 80.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 |
| 75.00 | 76.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 |
| 65.00 | 75.00 | 20000.00 | 200.00 | 0.00 | 1.00 | 1.00 |
| 65.00 | 80.00 | 20000.00 | 200.00 | 1.00 | 2.00 | 3.00 |
| 65.00 | 75.00 | 5000.00 | 100.00 | 0.00 | 1.00 | 1.00 |
| 65.00 | 75.00 | 50000.00 | 1000.00 | 0.00 | 1.00 | 1.00 |
| 50.00 | 75.00 | 20000.00 | 200.00 | 1.00 | 1.00 | 1.00 |
| 50.00 | 75.00 | 20000.00 | 400.00 | 1.00 | 2.00 | 1.00 |
| 50.00 | 75.00 | 20000.00 | 600.00 | .08 | 2.00 | 1.00 |
| 50.00 | 75.00 | 20000.00 | 500.00 | .40 | 2.00 | 1.00 |
| 50.00 | 75.00 | 30000.00 | 500.00 | .40 | 2.00 | 1.00 |
| 60.00 | 75.00 | 10000.00 | 120.00 | 0.00 | 1.00 | 1.00 |
| 60.00 | 75.00 | 20000.00 | 240.00 | 0.00 | 1.00 | 1.00 |
| 60.00 | 75.00 | 30000.00 | 360.00 | 1.00 | 1.00 | 1.00 |
| 60.00 | 75.00 | 25000.00 | 300.00 | 1.00 | 1.00 | 1.00 |
| 60.00 | 75.00 | 22500.00 | 270.00 | 1.00 | 1.00 | 1.00 |
| 60.00 | 75.00 | 21000.00 | 220.00 | 0.00 | 1.00 | 1.00 |

* MODE: 1 STABLE
2 HEATING
3 COOLING

** OPTION: 1 CLEAR GLASS
2 SOLAR FILM

Figure 3. Sample output from controller simulation program

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AUTOMATED CONTROL OF LIGHTING AND FENESTRATION

**5. AUTHOR(S)**

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**6. PERFORMING ORGANIZATION** *(If joint or other than NBS, see instructions)*

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**10. SUPPLEMENTARY NOTES**

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

**11. ABSTRACT** *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This paper describes an automatic system for controlling the lighting and window shading in a commercial building. The system utilizes a microcomputer to monitor solar radiation and illumination levels and interior and exterior air temperatures, processing the input parameters to determine the optimum lighting level, window area, and solar film position to minimize building heating and cooling loads due to windows and lighting. The control methodology and logical flow are presented, along with a sample control program written in FORTRAN. The response of the system to various combinations of weather conditions is examined.

**12. KEY WORDS** *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

automatic control; daylighting; lighting control; microprocessor; window management

**13. AVAILABILITY**

☒ Unlimited
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